MACHINE ARCHITECTURE

Objectives Of This Module

In this module you will learn about the internal workings of the computer and how programs are executed inside the machine. Each part's role in the computing process will be explained and then demonstrated in two sample assembly language programs. You will also learn about the different number systems that are used when programming in assembly language.

Overview

1. Assembly Language and Machine Code.
   This section compares an assembly language routine with a similar program written in BASIC. In both cases the routine prints characters on the screen, however, each routine looks quite different and the difference in the performance of the routines is noteworthy.

2. Number Systems and Conversion.
   Here you will compare the three numbering systems, decimal, hexadecimal, and binary, used by the computer. Exercises in numeric conversion from one number system to another will prepare you for accessing memory in assembly language programs.

3. Machine Memory.
   This section will answer questions such as: "What is memory? How is it organized? Which parts can I use?"

4. Central Processing Unit.
   The 6502 is responsible for all that goes on inside the computer. This section explains six major components of the CPU and their role in processing programs.

5. Additional Chips.
   As you may know, the Atari features three additional chips to enhance the computer's graphics and sound capabilites. Each chip will be explained briefly.

Prerequisite Concepts

1. You must know the purpose of the PEEK and POKE statements and how to use them in BASIC.

Materials Needed

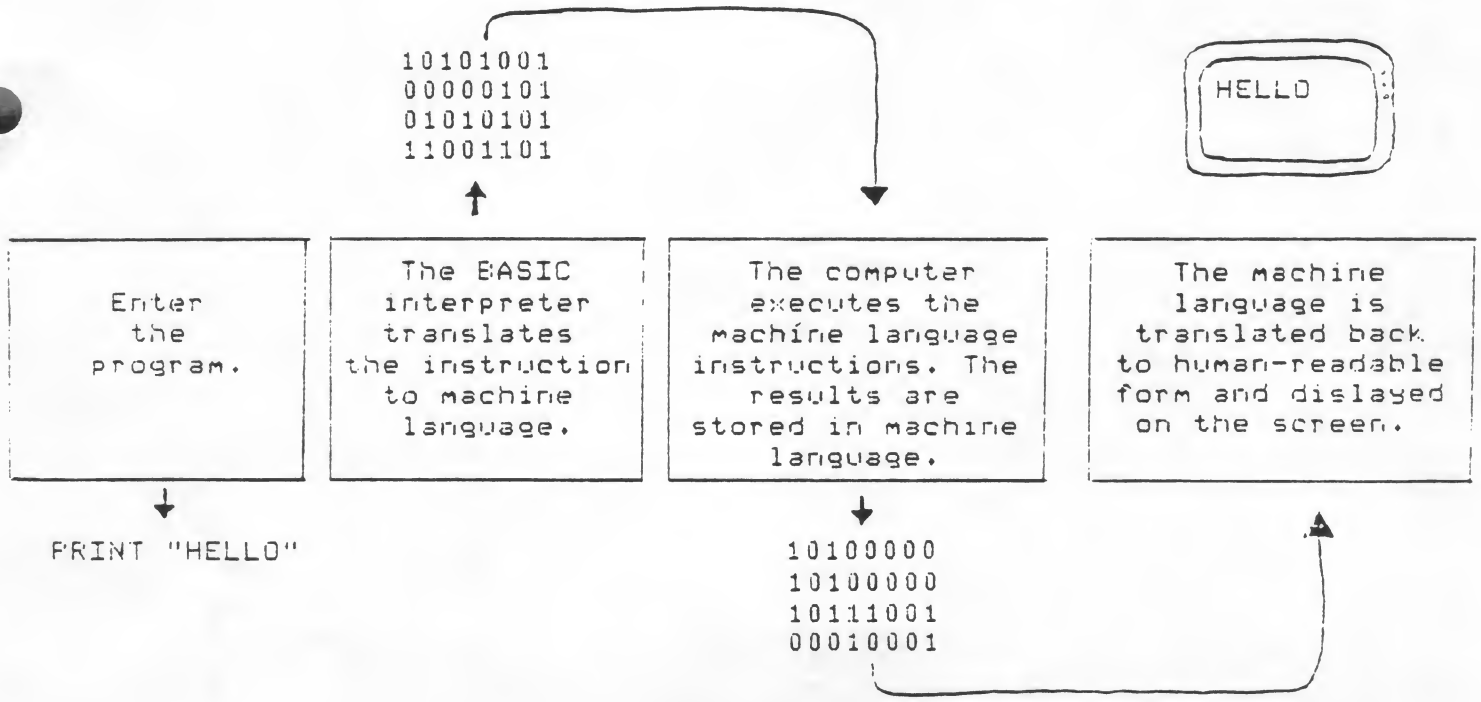
1. A BASIC cartridge.
2. An Assembler Editor cartridge.
3. An Advanced Topics Diskette.

Assembly Language and Machine Code

In this section you will use an assembly language routine to print words on the screen. You will POKE the assembly language routine into memory from a BASIC program and RUN it using the USR function.

When you type the instruction PRINT "HELLO" into your computer, the results of the PRINT statement appear on the screen so quickly that little work seems to be required on the part of the computer. However, in reality the computer goes through numerous steps merely to print "HELLO" on the screen. Below is a diagram of the steps the computer takes to execute a PRINT statement.

Diagram 1



First the instruction must be translated to machine code. The second box in the sequence represents the BASIC interpreter. The interpreter is a program that is permanently stored in memory and converts your BASIC program to ones and zeros (machine language) when you RUN your

program. Ones and zeros are all your computer really understands. The ones and zeros each represent the presence or absence of an electrical charge in the circuitry of the computer. By grouping the ones and zeros together into groups of eight we can represent more information than we could with just a one or a zero. Each segment of eight ones and zeros means something specific to the computer. For example, when the computer prints letters on the screen, 00101000 is the code for an "H," and 00100101 is the code for an "E." Each 1 and 0 is called a "bit," and each eight bit series is called a "byte."

```
          1 = A Bit
   10101010 = A Byte  (8 Bits)
```

Thus, it is the job of the BASIC interpreter to translate your BASIC program into bytes of information that the computer can understand. Programs in all languages must eventually be translated to machine code in order for the computer to execute them.

The computer works quickly and efficiently on a steady diet of ones and zeros. However, people find ones and zeros quite difficult to work with, especially when they are strung together in groups of eight ones and zeros. BASIC is much easier to work with because the instructions are in English. However, we are not getting something for nothing. We get the convenience of easy to use instructions in BASIC, but we forfeit speed and memory space. This is because BASIC programs must be translated to machine language each time they are executed. Assembly language captures the speed and efficiency of machine language while using more English-like instructions. Assembly language uses three letter instructions which are abbreviations or "mnemonics" for the functions they perform.

Now, for purposes of comparison, take a look at the three programs listed in Diagram 2 on the following page. Don't worry if you do not understand the programs. The purpose of Diagram 2 is to show you the differences among BASIC, assembly Language, and machine language programs. The three programs each print "HELLO" on the screen.

Diagram 2

BASIC PROGRAM

```
10 PRINT "HELLO"
```

****

ASSEMBLY LANGUAGE PROGRAM

```
          10 ;PRINT A MESSAGE ON THE SCREEN BY
          20 ;PLACING THE CODED NUMBERS FOR
          30 ;EACH CHARACTER DIRECTLY IN SCREEN
          40 ;MEMORY    FILE : TEXT
          50 ;*********************************
          60 ;
         100          *=$600
A905     110          LDA #5          ;MESSAGE LENGTH
85CD     120          STA $CD         ;STORE COUNTER
         130 ;
         140 ;$CD IS A FREE BYTE ON THE ZERO PAGE.
         150 ;THE MESSAGE LENGTH IS BEING STORED THERE.
         160 ;
A000     170          LDY #00         ;COUNTS EACH LETTER
B91106   180 LETTER   LDA $611,Y      ;GET THE NEXT LETTER
9158     190          STA ($58),Y     ;PUT LETTER ON SCREEN
C8       200          INY             ;INCREMENT LETTER COUNTER
C4CD     210          CPY $CD         ;THE END OF THE MESSAGE?
D0F6     220          BNE LETTER      ;NO?  GET ANOTHER LETTER
60       230          RTS             ;RETURN
28       240          .BYTE 40,37,44,44,47
25 2C 2C 2F
```

****

MACHINE LANGUAGE PROGRAM (BINARY CODE)

```
10101001          11001000
00000101          11000100
10000101          11001101
11001101          11010000
10100000          11110110
00000000          01100000
10111001          00101000
00010001          00100101
00000110          00101100
10010001          00101100
01011000          00101111
```

The three programs perform the same function. The programs each print "HELLO" on the screen. The program at the top of the page is obviously in BASIC. The program at the bottom of the page is in machine language. The machine language program lists the specific steps the computer must complete to print "HELLO." The program in the middle of the page is in assembly language. The instructions in assembly language still tell the computer each step to take in printing HELLO, but the instructions are much easier to work with since they are abbreviations for the operations to be performed rather than numbers. Once an assembly language program is written, it is translated to machine language and the machine language version is saved. Whenever the program is run again, the machine language version of the program is run rather than translating the program each time the program is executed. Thus, assembly language enables the programmer to benefit from the speed and control of machine language which is not available in BASIC, while also using more understandable instructions than in machine language.

Assembly language is made up of three-letter instructions that are abbreviations for a command. For example, the second to the last line of the assembly listing in Diagram 2 contains an "RTS" instruction. The RTS tells the computer to "ReTurn from the Subroutine." In this case the return is to a BASIC program. An RTS is comparable to a "RETURN" in BASIC. The instruction just above the RTS, "BNE," stands for "Branch Not Equal to zero," which is similar to an "If ... THEN" statement in BASIC.

Just as a BASIC program must be interpreted, the assembly language program also must be converted to machine language. Look closely at the assembly language routine in Diagram 2. Just to the left of the assembly language program are peculiar combinations of letters and numbers. Notice for example, Line 110 contains A905 to the left of the LDA #5 instruction.

Hexadecimal Machine Code	Line #	Assembly Instruction	Remark
A905	110	LDA #5	;MESSAGE LENGTH

This seemingly unintelligible notation is the machine language version of the assembly language program in hexadecimal (base 16). Instead of being displayed in ones and zeros (base two), now the machine language code is shown in base 16. (This will be explained in more depth in the Number Systems and Conversion section.) A machine language program can be represented in binary or hexadecimal numbers. Hexadecimal is used as a shorthand to binary. The values are the same, but the notation varies, just as "twenty-five" and 25 are different ways of recording the same amount on a check. The A905 in the assembly language version is the same as the 10101001 and 00000101 in the first two lines of the binary code listing in Diagram 2. We have two ways of representing the same value.

Hexadecimal		Binary	Assembly Language Instruction
A9	=	10101001	(LDA)
05	=	00000101	(5)

Machine language is the specific set of steps the computer must take to execute the program. It can be represented in binary numbers (base 2) or hexadecimal numbers (base 16).

It is also possible to POKE the decimal values of the machine language program into memory from a BASIC program. Listed on the following page are the binary, hexadecimal, and decimal equivalents for the machine language program. Note on the first line that $01101000=68_{16}=104_{10}$. All three numbers represent the same value. The program still prints "HELLO" on the screen. The first few values in this version, however, are slightly different from those in Diagram 2 to account for running the program from BASIC.

Diagram 3

Machine Code

Binary	Hexadecimal	Decimal
01101000	68	104
01101000	68	104
01101000	68	104
11000101	85	133
11001101	CD	205
10100000	A0	160
00000000	00	0
10111001	B9	185
00010100	14	20
00000110	06	6
10010001	91	145
01011000	58	88
11001000	C8	200
11000100	C4	196
11001101	CD	205
11010000	D0	208
11110110	F6	246
01100000	60	96
00101000	28	40
00100101	25	37
00101100	2C	44
00101100	2C	44
00101111	2F	47

Since assembly language is frequently used to enhance or speed up a BASIC program, first we will run the machine language routine from a short BASIC program. Turn to Machine Architecture Worksheet #1.

Machine Architecture Worksheet #1

** Your computer should have a BASIC cartridge in it. **

1. Load the program on your Advanced Topics Diskette entitled "MESSAGE".

Type: LOAD "D:MESSAGE"

LIST the program. The program listing you see on the screen should match the code in Diagram 4 on the following page.

The function of this program is to POKE the machine language routine which prints HELLO on the screen into memory. The machine language program is contained in DATA statements on lines 440-460. Since BASIC uses decimal numbers, the machine language program must be listed in base 10. (If you look back at Diagram 3 on page 7, you will find a list of the binary, hexadecimal, and decimal equivalents for the machine language version of this program.) The BASIC program reads the machine language data, one number at a time, and stores it in memory. The USR function on line 390 turns the computer's attention to the machine language program in memory to be executed. USR acts like a GOSUB in BASIC, however, the USR sends the computer to a machine language subroutine stored in memory. Take a moment to read the comments accompanying the program.

Diagram 4

```
10 REM *                PRINT MESSAGE
15 REM *
20 REM *      THE DECIMAL VALUES FOR A MACHINE LANGUAGE
25 REM *      SUBROUTINE ARE POKED INTO MEMORY.  THE
30 REM *      ROUTINE PRINTS HELLO ON THE GRAPHICS 0
35 REM *      SCREEN.  USE THE INTERNAL CHARACTER
40 REM *      SET VALUES TO CHANGE THE MESSAGE DATA ON
45 REM *      LINE 460.
50 REM ************************************************************
80 REM
100 COUNTER = 0:REM INITIALIZE COUNTER FOR MESSAGE LENGTH
110 PROGRAMLEN = 17 :REM PROGRAM LENGTH IS 18 BYTES (0-17)
120 REM
130 REM *  LINES 160-190 READ THE DATA FOR THE MACHINE LANGUAGE
140 REM *  ROUTINE ON LINES 440-450 AND POKE THEM INTO MEMORY
150 REM
160 FOR INSTRUCTION = 0 TO PROGRAMLEN
170 READ CODE
180 POKE 1536+INSTRUCTION, CODE
190 NEXT INSTRUCTION
200 REM
210 REM *  NOW READ THE MESSAGE DATA ON LINE 460.
220 REM *  WHEN OUT OF MESSAGE DATA GOTO 320 VIA TRAP.
225 REM *  COUNTER FINDS THE LENGTH OF THE MESSAGE.
230 REM
240 READ MESSAGE
250 TRAP 320
260 COUNTER = COUNTER + 1
270 REM
280 REM *  POKE THE MESSAGE INTO MEMORY FOLLOWING THE MACHINE
290 REM *  LANGUAGE ROUTINE
295 REM
300 POKE 1555+COUNTER, MESSAGE
310 GOTO 240
320 GRAPHICS 0 : PRINT "     ":REM ACCOUNT FOR BASIC BUG
330 REM
340 REM *  CALL USES THE USR FUNCTION TO GOSUB TO THE MACHINE
350 REM *  LANGUAGE ROUTINE STARTING AT 1536. THE LENGTH OF THE
360 REM *  MESSAGE IS PASSED TO THE ASSEMBLY ROUTINE IN
370 REM *  COUNTER.  WHEN DONE THE COMPUTER RETURNS TO BASIC.
380 REM
390 CALL = USR (1536,COUNTER)
400 REM
410 REM *  LINE 440 PASSES THE LENGTH
420 REM *  OF THE MESSAGE TO THE ASSEMBLY ROUTINE.
425 REM *  LINES 440-450 HOLD THE MACHINE LANGUAGE ROUTINE.
430 REM *  LINE 460 HOLDS THE DATA FOR HELLO
435 REM
440 DATA 104,104,104
450 DATA 133,205,160,0,185,20,6,145,88,200,196,205,208,246,96
460 DATA 40,37,44,44,47
470 REM *  EXTEND YOUR MESSAGE ONTO ANOTHER DATA LINE IF NECESSARY
```

2. RUN the MESSAGE program. HELLO should appear in the upper left hand corner of your screen.

3. The DATA on line 460 contains the values for the letters that will be printed on the screen. The machine language routine places the values for the letters directly into memory locations which are reserved for the video screen. By storing the letter in screen memory, the letter is put on the screen. Take a few minutes now to construct your own message. First plan your message below. You needn't restrict your message length to the lines provided below. Your message can be up to 60 characters in length.

Letters:

---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----

Numbers:

---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----

To POKE values directly into screen memory, as this program does, you must use the decimal values for the Internal Character Set. You will find a chart of the internal character set and its values on Chart #1 at the back of this module. Record the internal character set value below each of the letters in your message. These numbers represent the data for your message. Replace the decimal numbers on line 460, which represent the word HELLO, with the values for your message.

After you have double checked your typing, you should SAVE your program before running it. Programs in assembly language can "crash" easily. Generally it is a good idea to SAVE your programs each time major changes are made before running the program. SAVE your edited version of the MESSAGE on your work disk. Then RUN the program. Your message should appear in the upper left hand corner of the screen. Experiment with different messages.

At this point you are probably wondering, "Why bother with all these confusing numbers to accomplish something so easily done in BASIC?" Ordinarily, you would not use an assembly language routine just to print letters on the screen. The BASIC PRINT statement is much better suited to that purpose. However, when speed is a factor, assembly language is much more appropriate. Turn to Machine Architecture Worksheet #2 for a comparison of the execution speed of an assembly language program with a BASIC program.

Machine Architecture Worksheet #2

1. In the space below write a simple BASIC program that INPUTs a letter from the keyboard and fills the entire graphics 0 screen with that letter. Write your program to fill 874 locations on the graphics 0 screen. There are 960 locations on the graphics 0 screen, but you should leave one line to prompt your user to PRESS ANY KEY and get the INPUT character. An example of the program is in the "SCRNFULL" file on your Advanced Topics Diskette.

2. RUN your program and record how long it takes to fill the screen. _____seconds

Now let's compare your BASIC program with a similar program done in assembly language. Once again, the machine code for an assembly routine will be POKEd into memory from BASIC.

3. RUN the BASIC program called "FILLSCRN" on your Advanced Topics Diskette.

Type: RUN "D:FILLSCRN"

Press any key and then press another. Can you time how fast the screen fills up with a new character? _____

Summary

Because assembly language programs specify what the computer needs to do step-by-step, the code is more detailed and takes much longer to program. However, in some situations the increased speed of an assembly routine outweighs this disadvantage. For example, the superior graphics animation that one can get with assembly language is well worth the extra time spent programming.

Key Concepts

Assembly Language: The programming language closest to machine language. Assembly language consists of three-letter abbreviated instructions called mnemonics.

Binary Numbers: Base 2. The only digits used in base 2 are 1 and 0. When binary numbers are used to represent machine language, each digit in the binary number is referred to as a bit. Binary numbers are well suited to representing data in the computer because the computer is a two state system. The computer only recognizes the presence or absence of an electrical charge. A one represents the presence of a charge and a zero represents the absence of a charge.

Byte: Eight bits or binary digits make one byte. (eg. 11010111)

Hexadecimal Numbers: Base 16. Hexadecimal digits range from 0 through F. The letters A through F are equivalent to the decimal numbers 10 through 15. Hexadecimal numbers are commonly used to represent machine language programs.

Machine Code: Step-by-step instructions for the computer, represented in hexadecimal, binary, or decimal code when POKEd into memory from BASIC.

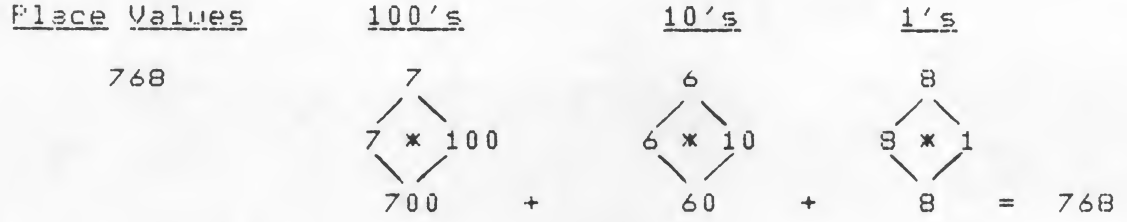
USR: A BASIC function that enables you to run an assembly language routine in memory from a BASIC program.

NUMBER SYSTEMS AND CONVERSION

In this section you will learn how to recognize and represent hexadecimal and binary numbers. It is necessary to understand these numbering systems if you wish to understand how the computer works and to pursue assembly language programming. All data in the computer is represented and manipulated in the form of electrical currents. We represent the presence of an electrical charge with a 1. Zero is used to represent the absence of a charge. Since the binary number system uses two symbols, 0 and 1, it is especially well suited to representing data in the computer. The computer does all of its calculations in binary. However, since numerous ones and zeros are difficult for people to work with, computer data is listed in hexadecimal for a more condensed and concise representation of the data. Thus, you must be knowledgable in both the binary and hexadecimal number systems to program in assembly language.

All numbering systems follow a similar scheme. The value of a number is based on the sequence of the digits in the number. So, to understand base 2 and base 16, a quick review of what you already know about base 10 may be useful.

In base 10 we know that the digits 0 through 9 are used. The numbers 0-9 are the ten different symbols that have been selected to represent the ten different digits in base 10. In order to represent larger numbers than any one digit in a number system can represent, we assign place values to each location a digit occupies. For example, consider the three digit number 768. The 8 is in what we call the ones column. So we have 8 ones. To the left of the ones column is the tens column. There are 6 tens in 768. And of course the 7 is in the hundreds column. Since we are in base 10, each column to the left is ten times the value of the previous column.



Hexadecimal Numbers (Base 16)

In base 16, in order to have 16 different symbols to represent the 16 different digits, the numbers 0 through 9 and the letters A to F are used. Thus, in base 16 the digits range from zero through F. The letters A through F represent the decimal numbers 10-15. Below is a list of the hexadecimal digits and their base 10 equivalents.

Hexadecimal	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
Decimal	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

The decimal number sixteen is represented as $10 in hexadecimal. The dollar sign preceeding the number indicates that the value is in base 16. The number $10 indicates one sixteen and zero ones. In base 16 the place values are sixteen times the preceeding place value.

Hexadecimal Place Values:	16^3	16^2	16^1	16^0
Decimal Equivalents:	4096	256	16	1

The rightmost column is the ones column. The next column to the left holds the number of sixteens in the total value. The third column to the left holds the number of 256's (or 16^2's) and so on. Consider the example of hexadecimal to decimal conversion below:

Place Values	4096's	256's	16's	1's
$600	0	6	0	0
	0 * 4096	6 * 256	0 * 16	0 * 1
	0 +	1536 +	0 +	0 = 1536

Multiplying each digit by its place value and adding up the products gives you the decimal equivalent to a hexadecimal number. The sum 1536 is the decimal memory location we used for the machine language routine in the MEMORY program. So the program was stored at $600 in memory. Hexadecimal numbers are used to load and access memory locations in assembly language. Look over this next example of hexadecimal to decimal conversion.

Place Values	4096's	256's	16's	1's
	9	C	4	0
$9C40	9 * 4096	12 * 256	4 * 16	0 * 1
	36864 +	3072 +	64 +	0 = 40000

The starting address of memory for the graphics 0 screen is decimal 40000 or $9C40. Turn to Machine Architecture Worksheet #3 for some practice problems on hexadecimal to decimal conversion.

Machine Architecture Worksheet #3

Hexadecimal to Decimal Conversion

1. Convert $1?3F to a decimal number.

Place Values	4096's	256's	16's	1's
$1_3F	1	_	3	F
	_ * 4096	10 * 256	_ * 16	F * 1
	_____	+ _____	+ _____	+ _____ = 6719

2. Convert the following hexadecimal numbers to decimal numbers.

1.	$23	_____	9.	$00	_____
2.	$6F	_____	10.	$B7	_____
3.	$6D	_____	11.	$A9	_____
4.	$70	_____	12.	$BA	_____
5.	$75	_____	13.	$A1	_____
6.	$74	_____	14.	$B2	_____
7.	$65	_____	15.	$A4	_____
8.	$72	_____			

3. The numbers you just converted to decimal numbers were selected because they represent the letters of a message. To find out what the message is, you will use your answers from problem number 2 as DATA in the MESSAGE program. First, load the file called "MESSAGE" on your Advanced Topics diskette.

Type: LOAD "D:MESSAGE"

Now type in the decimal numbers from problem 2 on line 460 of the MESSAGE program. Leave the word DATA at the beginning of the line, but replace the numbers for HELLO with your decimal answers from above. Be sure to separate each number with a comma, starting with your answer to #1 and ending with your answer to #15. If your answers are correct,

you should get a message in the upper left hand corner of the screen. The numbers you are using to represent the letters are from the Internal Character Set. A chart of the values for the internal character set appears at the back of this module.

4. Can you write a BASIC program to do conversions from hexadecimal to decimal for you?

NOTE: The hexadecimal and binary numbering systems are quite confusing at first. The more experience you have using each of the two systems, the easier they will be to understand.

Decimal to Hexadecimal Conversion

Finding the hexadecimal equivalent to a decimal number is a little more difficult. But as you begin to write assembly language routines, you need to identify where your routine will go in memory. In assembly language, locations in memory are identified with hexadecimal numbers. In BASIC you give the memory location in decimal.

Let's begin by looking over an example of converting the decimal number 40000 to a hexadecimal number. You already know the answer from the hexadecimal to decimal conversion section, so you will know if your calculations are on track.

First, divide 40000 by 16.

```
    2500
16 | 40000        $_ _ _ _
     32
      80
      80
       00
       00
        00
        00
         0
```

The remainder goes in the right most column of the hexadecimal value. So far, we have ? ? ? 0. Now divide 2500, the answer you got from your previous division, by 16. Complete the division.

```
    15
16 | 2500        $_ _ 4 0
     16
      90
```

You should have gotten 156, with a remainder of 4. The 4 goes in the second column from the right, the 16's column.

Divide again! This time, 156 is divided by 16. Finish the problem.

```
      9
16 ) 156          $ _ _ 4 0
     144
      12
```

The remainder of 12 (a "C" in hexadecimal) goes in the 256's column. Finally, since 9 is not divisible by 16, it goes in the next column to the left, the 4096's column. So 40000 = $9C40.

To check your answer simply multiply each digit by its place value and add.

Place Values:	4096's	256's	16's	1's
$9C40	9	C	4	0
	9 * 4096	C * 256	4 * 16	0 * 1
	36864 +	3072 +	64 +	0 = 40000

Complete the decimal to hexadecimal conversions on Machine Architecture Worksheet #4.

Machine Architecture Worksheet #4

Decimal to Hexadecimal Conversion

1. Complete the following conversion. To check your answer simply multiply each digit of the hexadecimal number by its place value and add up the products.

2598 = $__ __ __ __

```
      162
   ------
16 | 2598      16          16
     16
     ---
      99
      96
      --
       38
       32
       --
        6
```

2. Convert the following decimal numbers to hexadecimal.

133 = _____

205 = _____

160 = _____

0 = _____

185 = _____

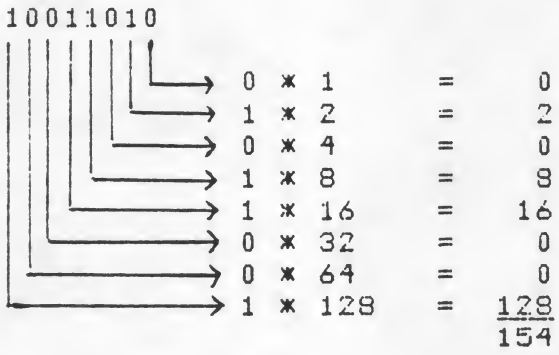
The decimal numbers you just converted to hexadecimal were the first six numbers in the DATA statement on line 450 of the MESSAGE program. To check your answers look back at the machine language code for the MESSAGE program in Diagram 3 on page 7. Your answers should correspond to the fourth through the eighth numbers listed in the hexadecimal column. The first three numbers are not used because they are the same. Those numbers are necessary for running the machine language routine from BASIC.

Binary Numbers

Binary numbers are also used represent the data and the instructions the computer executes. Base 2 requires only two different symbols for digits. The digits used in base two are zeros and ones. Just as in hexadecimal and decimal notation, the total value of a number is based on the placement of the digits. The place value of each adjacent column to the left is increased exponentially by one, as shown below.

Binary Place Values:	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Decimal Equivalents:	128	64	32	16	8	4	2	1

To get the decimal equivalent to a binary number, simply multiply the digit by its place value and sum up the products, just as you did when converting a hexadecimal value to decimal. Study the example of binary to decimal conversion below.



Now turn to Machine Architecture Worksheet #5 and complete the conversions.

Machine Architecture Worksheet #5

1. Convert the following binary numbers to decimal. The table of decimal equivalents to the binary place values below should be helpful.

Binary Place Values: 128 64 32 16 8 4 2 1

11111111 = _____ = The largest number that can be represented by one byte.

00100001 =	_____	00111010 =	_____
01100001 =	_____	01111010 =	_____
10100001 =	_____	10111010 =	_____
11100001 =	_____	11111010 =	_____

2. Load the MESSAGE file on your Advanced Projects Diskette.

Type: LOAD "D:MESSAGE"

Type in the decimal numbers you got in the above conversions as data on line 460. Remember to put commas between the decimal values. Then RUN the program.

You should see various forms of the letters "A" and "Z" in the upper left hand corner of your screen. You have POKEd values of the internal character set into screen memory.

3. Record the letter as it appears on the screen next to the corresponding decimal number you got at the top of this worksheet.

4. Look back at the binary numbers you converted to get the different A's. Notice that the only difference in the bits (ones and zeros) of the four numbers are the two bits on the far left. This is also true for the binary numbers you used for the various Z's you got. Those two bits are referred to as bits 6 and 7.

The positions of the digits in a binary value are numbered from zero to seven starting on the right.

A bit is said to be "set" if there is a one in the corresponding bit location. Otherwise, the bit is "clear," which means it contains a zero.

In the example above you can see that the base value the computer uses for a normal capital "A" is 33. Adding 64 to the 33 sets bit six of the bit pattern for a normal "A", because the place value for bit 6 is 2^6 or 64.

```
00100001 = 33 = A
01100001 = 97 = a
\/ \   /
64  33
```

This new value of 97 indicates to the computer that you want to print a lower case "a". Adding 197 to the base number for an "A", or setting both bits six and bit seven, results in the value for an inverse lower case "a".

```
11100001 = 197 = Inverse a
```

The base value of 33 (00100001) for an "A" remains the same. Bits 0-5 stand for the letter "A" and remain unchanged. Setting bit 6 to a one indicates to the computer that you wish to display a lower case letter. Setting bit 7 to a one indicates to the computer that you are representing an inverse character.

To learn more about how the computer recognizes the number 33 as an "A" and goes about printing an "A" on the screen, see the Internal Representation of Text and Graphics Module.

5. Regardless of which number base you are using, you need to be able to convert numbers back and forth between the different numbering systems. Now we will try converting decimal numbers to binary. First determine the largest binary place value that can be subtracted from the decimal number to be converted. Subtract the binary place value from the number and put a one in that place value in your binary number. For example, if the decimal number is 10, the largest binary place value that can be subtracted from 10 is 8. Subtract 8 from 10 and put a one in the eights column of the binary equivalent.

Binary Place Values:	128	64	32	16	8	4	2	1
10 - 8 = 2					1	0	1	0

The result of the subtraction was 2. Since there are no 4's in 2, put a zero in the 4's column. There is a 2 in 2, so put a 1 in the 2's column. There are no 1's left so put a zero in the one's column.

Convert the following decimal numbers to binary.

1. 133 = _____

2. 205 = _____

3. 160 = _____

4. 0 = _____

5. 185 = _____

6. 20 = _____

7. 6 = _____

8. 145 = _____

9. 88 = _____

10. 200 = _____

The decimal values you have just converted to binary numbers are the same numbers you typed in for DATA on line 460 of the MESSAGE program. Your binary answers should correspond to the fourth through the twelfth numbers listed in the binary code in Diagram #3 on page 7 of this module. Start with the fourth number because the first three are all the same (104).

Binary to Hexadecimal Conversion

We mentioned earlier that the computer represents data and does all of its computations in binary. However, when an assembly language program is converted to machine language, the machine language version will be listed in hexadecimal since hexadecimal numbers are easier to work with than binary numbers. Thus, in order to understand what is going on inside the machine you must be able to convert binary numbers to hexadecimal and vice versa.

Four binary digits are equal to one hexadecimal digit. The highest value that can be represented by four binary digits is 15.

1111 = 15 = $F

4 Bits = 1 Hexadecimal Digit

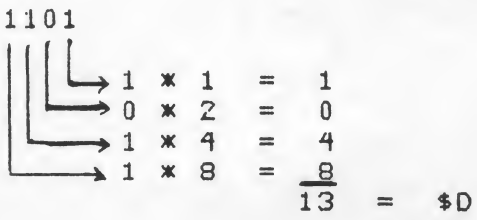
Eight binary digits are equal to two hexadecimal digits or one byte.

11111111 = $FF = one byte

Four bits or half a byte is called a "nybble."

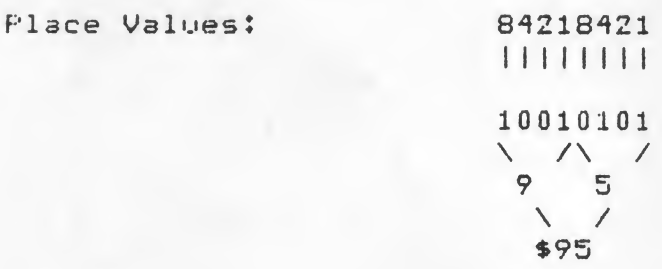
one nybble = one hexadecimal digit = $F

To convert a binary nybble to a hexadecimal digit, multiply each bit by its place to get the decimal equivalent. Then convert the decimal number to hexadecimal as shown below.



To convert an eight bit byte to hexadecimal, simply split the byte into two nybbles and treat each nybble as having place values of 0-8.

The following is an example of binary to hexadecimal conversion.



Try converting the binary numbers listed below to hexadecimal. Check your answers with a friend or your instructor.

10010101 = _____ 11111110 = _____

00101111 = _____ 00101100 = _____

Summary

1111 = 4 Bits
4 Bits = One Nybble

1111 = $F
4 Bits = One Hexadecimal Digit

11111111 = 8 Bits
8 Bits = One Byte

11111111 = $FF
One Byte = Two Hexadecimal Digits

BINARY, HEXADECIMAL, AND DECIMAL EQUIVALENTS

Binary	Hexadecimal	Decimal
00000001	$01	1
00000010	$02	2
00000011	$03	3
00000100	$04	4
00000101	$05	5
00000110	$06	6
00000111	$07	7
00001000	$08	8
00001001	$09	9
00001010	$0A	10
00001011	$0B	11
00001100	$0C	12
00001101	$0D	13
00001110	$0E	14
00001111	$0F	15
11110000	$F0	240
11111111	$FF	255
1111111111111111	$FFFF	65,535

A BASIC program which converts decimal numbers to hexadecimal and hexadecimal numbers to decimal is listed in Appendix H of the Atari BASIC Reference Manual.

There is a small conversion chart for hexadecimal to decimal conversion at the back of this module which may also prove to be useful.

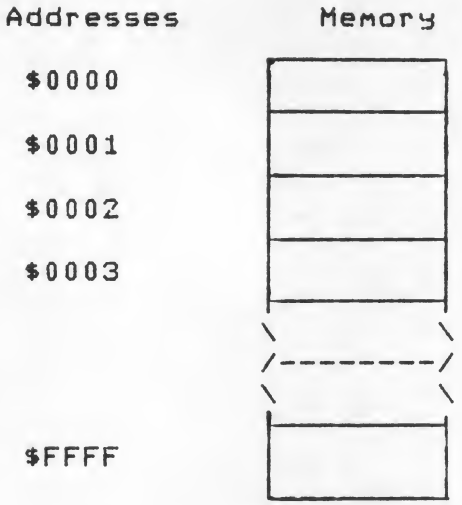
Machine Memory

Memory is a vital part of the computer. The 6502 processor, the brain of the computer, is only capable of holding and executing one instruction at a time. Thus, the processor relies on memory to hold data, the program to be executed, and the results of a program. In this section you will learn how memory is organized and how to access information stored in memory.

Memory in a computer can be thought of as a long, LONG stack of mail boxes. Each mail box can hold only one standard size envelope. In the Atari, each memory location holds one byte of information. When an assembly program is translated to machine language, each byte of the program is put in successive memory locations.

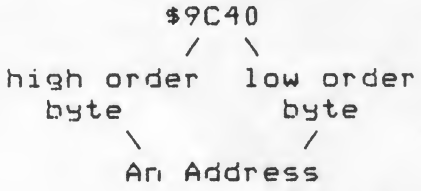
Assembly Language Program	Machine Language Version	Memory
		10101001
LDA #5	10101001	
	00000101	00000101
STA $CD	01010101	01010101
	11001101	11001101

To return to the mail box analogy, each mail box or memory location has an "address." An address is a hexadecimal number that identifies a memory location. Each memory location has a unique address. All memory addresses in the Atari are two bytes long. Remember that two hexadecimal digits are equal to one byte. Thus, all memory addresses are two bytes or four hexadecimal digits. The first mail box in memory has an address of $0000. The address of the next box in memory is $0001. In a computer which has 64K of memory the address of the last box in memory is $FFFF.



As you may have gathered from the Number Systems and Conversion section, $FFFF (or its binary equivalent 1111111111111111) is the largest two-byte hexadecimal number. If you were to add 1 to $FFFF, you would get $10000, which is a three byte number. All memory addresses in the Atari are two bytes.

Names are given to each of the two bytes that make up a memory address. Take the memory address $9C40. The two digits on the right, 40, are called the low order byte of the address. The 9C is in the position of the high order byte.

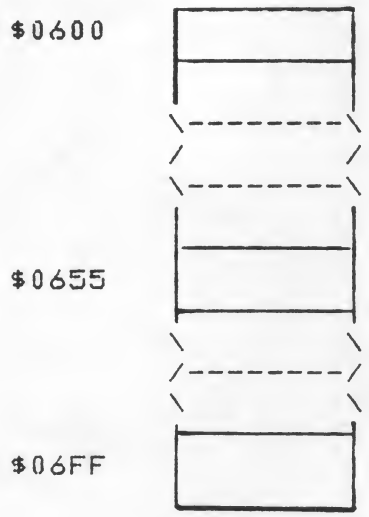


Instead of dealing with lots of individual boxes, convenient systems for dealing with memory in terms blocks of memory locations have been devised. One "page" of memory is made up of 256 memory locations. The addresses of the first page of memory range from $0000 - $00FF ($FF = 255). Thus, the addresses run from 0 to 255. If you count the zero address as one then you have 256 locations. The page of memory inwhich the addresses range form $0000 to $00FF is called the zero page. The high order byte of an address on the zero page is always $00.

$0000 - $00FF The high order byte is always $00 for addresses on the zero page.

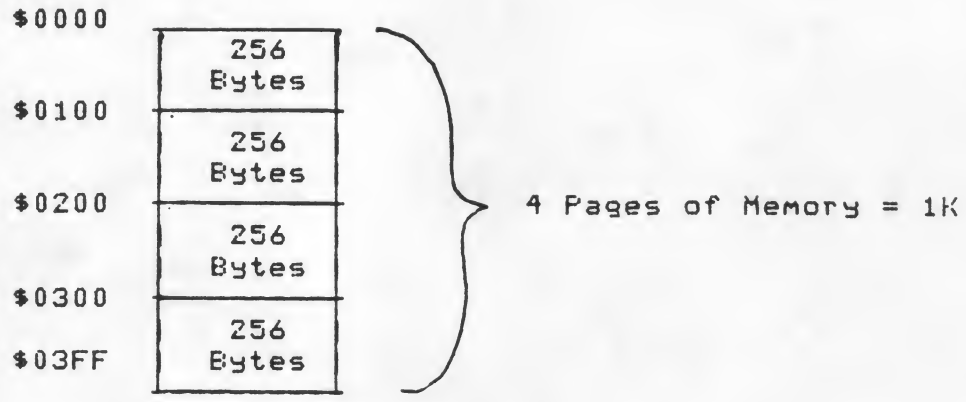
The addresses on page one of memory range from $0100 - $01FF. Therefore, the high order byte of all the addresses on page one is $01. The low order byte of the address indicates which of the 256 memory locations on that page of memory is being accessed. The address $0655 indicates the 55th location on page six in memory. See the diagram below:

Page 6 of Memory



Have you ever wondered why some programs include statements like Screen = PEEK(89)*256+PEEK(88)? In this case locations 88 and 89 contain the starting address of screen memory. Since addresses are two bytes long and individual memory locations can only hold one byte, addresses must be stored in consecutive memory locations. Location 89 holds the high order byte of the address. Location 88 contains the low order byte of the address. Since the high order byte of an address is the same as the page number, it is multiplied by the number of bytes on a page.

Chunks of memory are most commonly referred to in terms of the number of "K" of memory you have. The Atari 800 can access 64K of memory when all the memory cartridge slots are filled. What exactly is a "K" of memory? Four pages of memory are equal to 1K of memory.



To the programmer, 1K of memory is actually 1,024 bytes of memory locations, not 1,000.

```
  256   1 page of memory = 256 bytes or locations
 X 4    4 pages of memory
1024    1K of memory
```

A 48K computer has 49,152 memory locations.

```
  1024  1K of memory
 X 48   Number of K
49,152  Memory locations
```

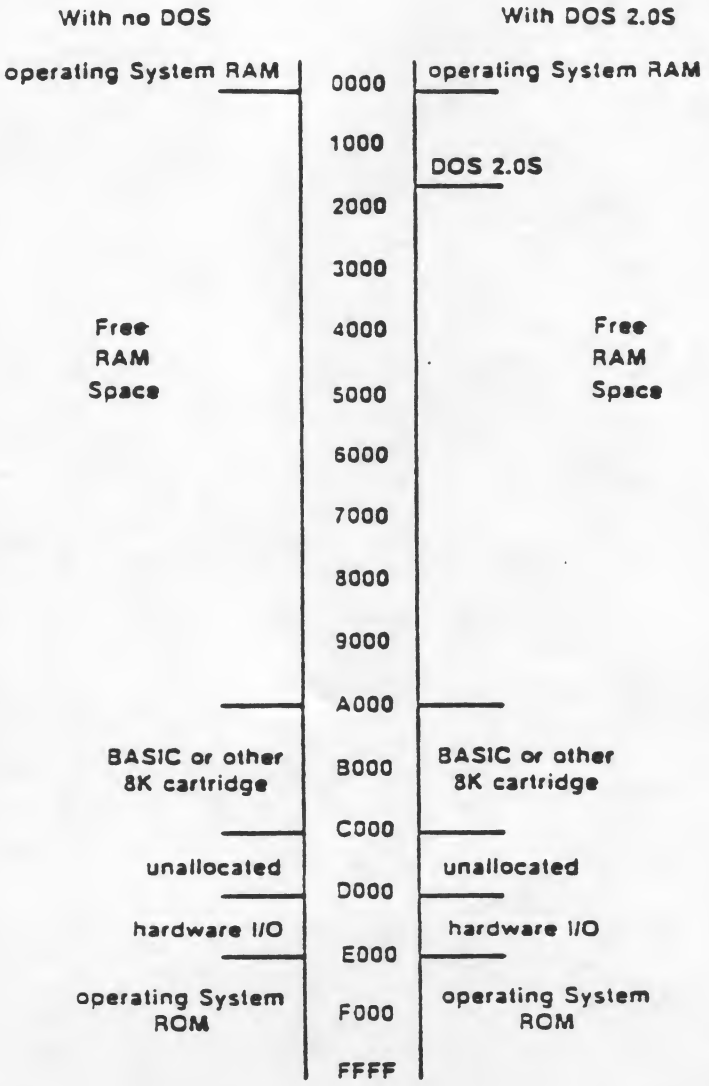
And a 64K machine has 65,536 memory locations.

```
  1024  1K of memory
 X 64   Number of K
 65536  Memory locations in 64K
```

If you count the first memory location as zero, the memory locations are numbered 0 through 65,535. The number 65,535 probably looks familiar. If you convert the decimal number 65,535 to hexadecimal, you will find that it equals $FFFF, the highest possible address in memory.

Not all 65,536 memory locations are available to the programmer. The area of memory where your programs and data are stored is called "RAM" or random access meemory. You can store anything you wish in random access memory as well as read data from those locations. Random access memory also is referred to as "read/write memory." You can think of read/write memory as being like a blackboard which you can write on, read from, or erase and start over. Diagrams which depict a computer system's memory organization is called a memory map. Take a look at the memory map of the Atari in Diagram 6 below. Right away you can see that there is quite a bit of free RAM available to you.

Diagram 6



The area of memory that is not free for the programmer to use is called "ROM" or read only memory. ROM contains machine language programs called the "operating system" that enable you to communicate with your computer and get information back. For example, when we press a key on the keyboard we rely on the programs in ROM to read the keypress and display the corresponding character on the screen. Another program in the operating system is the BASIC language translator which translates our BASIC programs to machine language so that they can be executed by the processor. The "operating system," also includes programs that provide access to the various input and output devices. "DOS," or the "disk operating system" programs, handle loading, copying, and saving files on disk, also resides in ROM. The computer will not let you store any of your own programs in ROM, because you would destroy the routines which enable the computer to process your programs. Instead, the routines in ROM are read and used continually as you use your computer. There is nothing a programmer can do which will damage or change ROM unintentionally. ROM, read only memory, can be thought of as a book inside the compwter. You can read from it, but you cannot change the print or the information in the book. Turn to Machine Architecture Worksheet #6 to look at the contents of a portion of RAM and ROM.

Machine Architecture Worksheet #6

You will need the Assembler Editor cartridge and the Advanced Topics Diskette to complete this worksheet.

Insert the Assembler Editor cartridge in slot A, where you ordinarily put the BASIC cartridge. Turn off your computer and boot your Advanced Topics Diskette. The word EDIT should be in the upper left hand corner of your screen. If not, reboot the system. Now you are ready to begin.

Although your computer has 65,536 memory locations, they are not all available to you. The memory available to the programmer is called "RAM" or random access memory. Random access memory is storage space in memory for your programs.

1. First, let's look at the contents of some RAM.

   Type: BUG and press <RETURN>
   Type: D4000,5000 and press <RETURN>

The "D" stands for display. You are displaying the contents of memory locations $4000 through $5000.

Based on what you saw, what is currently stored in locations $4000-$5000? _____

What do the zeros indicate?

---

2. Now turn to the memory map in Diagram 6 and locate $4000-$5000. How is that area of memory labeled on the memory map?

---

3. The areas of memory that are not free to the programmer are called "ROM" (read only memory) and are reserved for the computer. To see the contents of some ROM,

   Type: DF000,FFFF and press <RETURN>

All those numbers flying by are the machine code of the operating system. The operating system contains the machine language programs necessary for you to be able to use the various input and output devices with the computer. For example, a program in the operating system interprets a key press on the keyboard.

4. Now load the assembly language version of the MESSAGE program into memory. First type X to get back into the editor and then enter the file.

Type: X and press <RETURN>

Type: Enter #D:TEXT and press <RETURN>

5. You should see the word EDIT in the upper left hand corner of your screen.

Type: LIST 0,200 and press <RETURN>

6. You should see the assembly language routine we POKEd into memory in the MESSAGE program. Note that it begins with an asterisk followed by $600. In assembly language you must give the hexadecimal address of where you want your program stored in memory. The program was stored on page 6 -- page 6 is free RAM.

7. Type: ASM and press <RETURN>

The assembly language version is being "assembled" to machine code.

8. Type: BUG and press <RETURN>

We are going into the "debugger," which will enable us to peer into memory.

9. Type D600,615 and press <RETURN>

This will display the contents of memory from $600 through $615.

It should look like this:

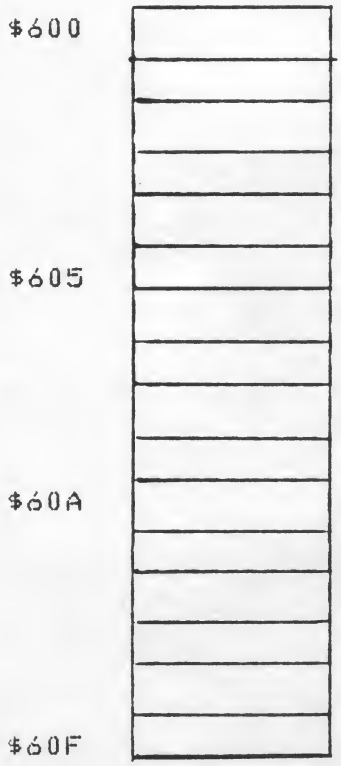
```
0600  A9 05 85 CD A0 00 B9 11
0608  06 91 58 C8 C4 CD D0 F6
0610  60 28 25 2C 2C 2F
```

The numbers on the left are the hexadecimal addresses of the memory locations. The memory locations are listed in groups of eight. So on the first line the two digits following 600 (A9) are the contents of memory location $600. The next two digits are the byte in $601.

$600 = A9
$601 = 05
$602 = 85

The second row lists the contents of eight consecutive locations starting at $608. OOPS! What happened between the second and the third lines where the starting addresses go from 608 to 610? Don't forget, the memory addresses are in hexadecimal. Line 608 lists the contents of memory locations 608, 609, 60A, 60B, 60C, 60D, 60E, and 60F.

10. Record each pair of hexadecimal values, as you see them on the screen, into each memory location of the memory map below. This is how your programs are stored in memory.



Summary

A Memory Address = Two Bytes = $9C40

$9C = The high order byte.

$40 = The low order byte.

The high order byte of an address indicates which page of memory the location is on.

The low order byte of an address indicates where the byte is located in the page of memory.

One page of memory = 256 locations.

One K of memory = 1024 locations.

Four pages of memory = 1K

Challenges

Take a look at some of the specific memory locations you have POKEd values into in the past. Load the assembler editor. From the EDIT prompt type BUG and press <RETURN> to enter the debugger. To see the contents of a memory location while in the debugger, you simply type D and the hexadecimal memory addresss.

To change or POKE a new value into a memory location from the debugger, type C for change followed by the address and what you wish to store there.

Type: C address < new contents and press <RETURN>

For example, from the debugger try typing, C2F3<4 and press <RETURN>

This changes the contents of memory location $2F3 (530 in decimal) to 4. Memory location $2F3 holds a value which indicates to the operating system whether characters are to be displayed on the screen right side up or up side down. When the operating system encounters a 4 in location $2F3 it inverts the letters.

In order to return the letters to an upright position,

Type: C2F3<2 and press <RETURN>

Take this opportunity to have a look through the Master Memory Map by Santa Cruz Educational Software. There are copies either in your classroom or in the camp library. Consult your instructor for where to get one. Experiment with changing the contents of some memory locations. Remember, you cannot harm the programs stored in ROM unintentionally so feel free to experiment.

The Central Processing Unit

At the heart of the Atari computer lies the 6502 microprocessor. The 6502 is also called the "central processing unit" or the CPU. The CPU is responsible for all that goes on within the computer. In this section the major components of the CPU will be discussed and each part's role in the computing process will be explained. At the end of the chapter you will have an opportunity to execute your first assembly language program.

If you could look inside your computer, you would find that the CPU itself is really quite small. The 6502 microprocessor consists of a tiny silicon chip (approximately 1/4" square) housed in a black plastic box approximately two inches by a half an inch.

The 6502 serves as the master controller or "brain" of the computer. One of its jobs is to execute the instructions in your program. However, the 6502 can hold and execute only one instruction at a time. For example, adding two numbers together is one operation which demands all of the CPU's attention until the computation is complete. Meanwhile, the rest of the instructions in your program, are stored in memory. In order to execute your program the 6502 "fetches" the instructions from memory one at a time. The CPU executes an instruction, stores the result in memory and fetches the next instruction. The "fetch cycle" is repeated until the program is completed. Memory enables the microprocessor to have easy access to your program so that successive instructions can be completed very rapidly. Thus, the CPU and memory work closely to perfom the main functions of the computer.

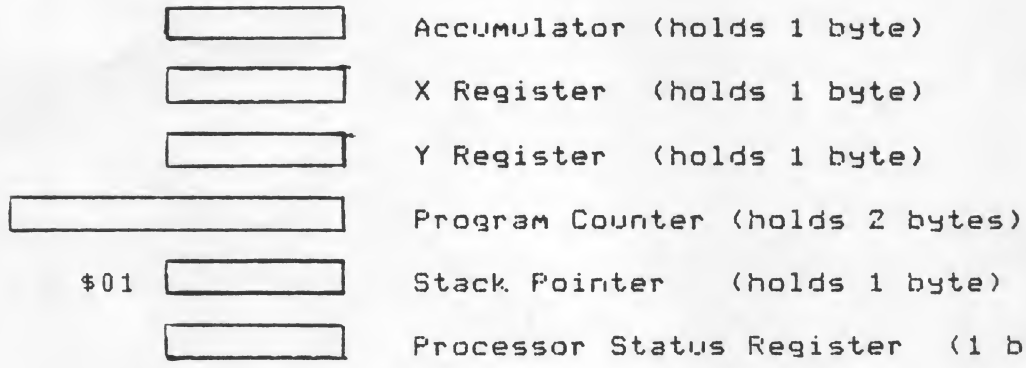
The link between memory and the microprocessor is a complicated set of wires called the "data bus."

Data Bus
Memory <----------> 6502

The 6502 is made up of six major components called "internal registers." A register is a temporary storage location. The registers in the CPU serve different functions. Diagram 7 illustrates the different registers of the 6502.

Diagram 7

6502 Model



The Accumulator:

Any number which is passed between memory and the CPU must be passed through one of three registers in the CPU: the Accumulator, the X Register, or the Y Register. The accumulator is the most commonly used register for data transfer. An instruction in assembly language, "LDA" or LoaD the Accumulator, instructs the CPU to load the accumulator with the contents of a specified memory location.

The accumulator holds one byte, as does one memory location. Because they are equal in size, data transfer from memory to the accumulator and vice versa is simple.

The accumulator is used in all arithmetic and logic operations. Whenever two numbers are to be added or subtracted, one of the two numbers must be loaded into the accumulator.

The X Register and the Y Register:

The X and Y registers each hold one byte and they also can be used to transfer data between memory and the CPU. However, the X and Y registers are more commonly referred to as "index registers", because programmers often use them as counters or "indexes" to a loop. In assembly language you can repeat instructions in a "loop" as you would in a BASIC program with a "FOR . . . NEXT" loop. To use the X register or the Y register as a counter to a loop, the program adds or subtracts one from the number in the index register each time

a set of instructions is repeated. The number in the index register indicates the number of times the loop has been executed.

Turn to Machine Architecture Worksheet #7 for a better look at how the internal registers are used. You will need a pencil to complete this worksheet.

Machine Architecture Worksheet #7

Let's look at an example of how the accumulator and the X register are used to execute a simple assembly language program. We don't expect you to understand what each assembly language instruction means in this exercise. Instead, we hope that you will learn more about the machine processing cycle by completing this worksheet. The program multiplies 4 times 5. The microprocessor multiplies by doing a series of additions. For example, to multiply 4*5, the computer adds 5, four times. In assembly language there are no instructions to multiply numbers. The 6502 only knows how to add or subtract.

4 * 5 = 5 + 5 + 5 + 5

The assembly language routine is listed below. In this example, the accumulator will hold the sum of the numbers being added. The X register will hold the counter for the number of times the addition loop has been repeated.

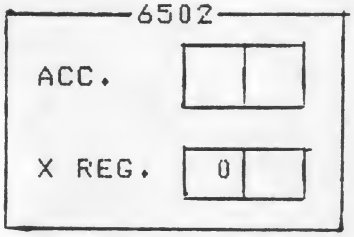
```
        ORG $600    ;ORIGINATE THE PROGRAM AT $600 IN MEMORY
        LDX #4      ;LOAD THE X REGISTER WITH COUNT OF 4
        LDA #0      ;LOAD THE ACCUMULATOR WITH ZERO
        CLC         ;CLEAR THE CARRY.  THIS WILL BE DISCUSSED LATER
ADD     ADC #5      ;ADD 5 TO VALUE IN THE ACCUMULATOR
        DEX         ;SUBTRACT ONE FROM COUNTER IN X REGISTER
        BNE ADD     ;IF COUNTER ISN'T ZERO ADD 5 AGAIN
        STA $060E   ;STORE THE ACCUMULATOR VALUE IN MEMORY
        BRK         ;BREAK
```

Imagine that you just loaded this program into memory and you are about to execute the program. You will step through the program and execute one instruction at a time just as the CPU would in executing the program.

LDX #4: Load the X Register with 4, which is stored ter the LDX instruction in memory. This sets the counter the number of additions that will be computed. Load the egister below with 4. Don't worry about the fact that some ry locations are empty.

MEMORY		
Address	Value	
$600	(LDX)	<——
$601	4	<——
$602	(LDA)	
$603	0	
$604	(CLC)	
$605	(ADC)	
$606	5	
$607	(DEX)	
$608	(BNE)	
$609		
$60A	(STA)	
$60B		
$60C		
$60D	(RTS)	
$60E		

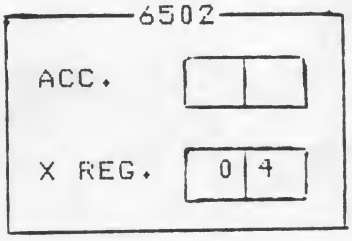
Load the X register with a 4.



2. LDA #0: Load the accumulator with the 0 which is stored in memory after the LDA instruction. This insures that the accumulator is cleared to zero before we begin adding. When a load instruction is executed a copy of the number stored in memory is placed in the register. Thus, after executing the LDA #0 instruction there is a zero in memory location $603 and in the accumulator.

MEMORY		
Address	Value	
$600	(LDX)	
$601	4	
$602	(LDA)	<——
$603	0	<——
$604	(CLC)	
$605	(ADC)	
$606	5	
$607	(DEX)	
$608	(BNE)	
$609		
$60A	(STA)	
$60B		
$60C		
$60D	(RTS)	
$60E		

Load the Accumulator with a 0.

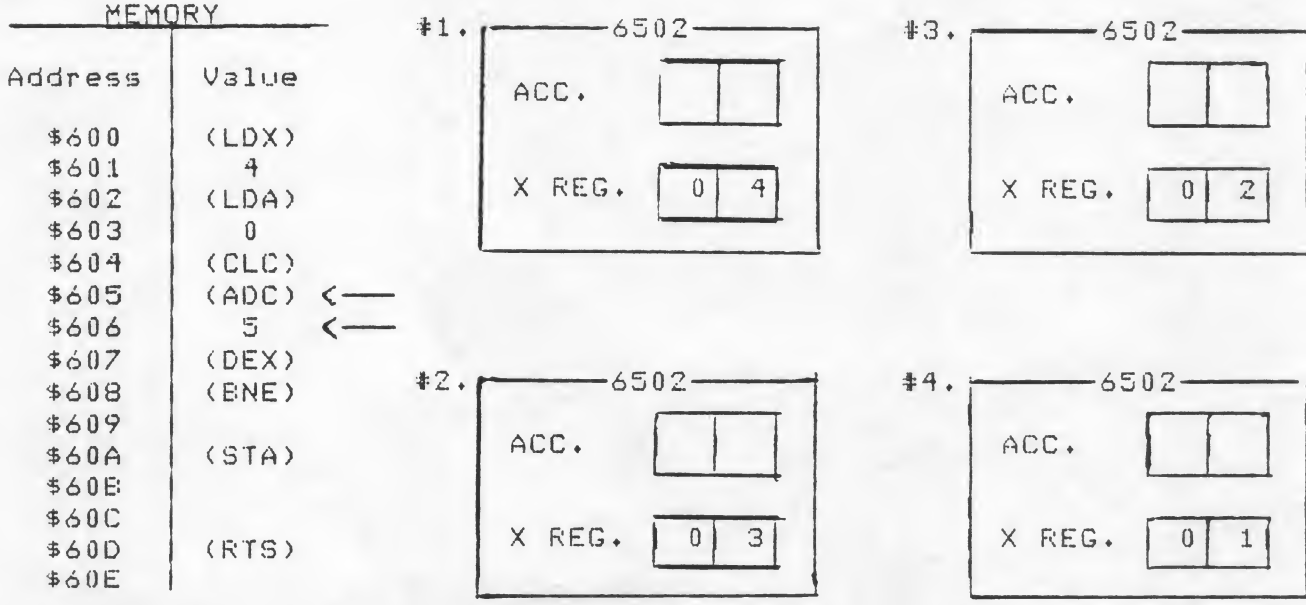


3. We will ignore the CLC instruction to the CPU for now.

4. ADC #5: Now add 5 to the number in the accumulator. This calculation is performed by the CPU. The answer is put in the accumulator.

If this is the first time you have executed this instruction, look back to the accumulator in number 2 above to see what is currently in the accumulator. Add 5 and store the new value in box #1 below and then continue with the next assembly language instruction.

Otherwise, fill in the boxes below in the order in which you execute this instruction. If this is the second time you have executed this instruction, add 5 to the value in the accumulator in box #1 and store the new value in the accumulator in box #2. Remember to use hexadecimal numbers.



5. DEX: An addition has been completed, so the X register is decremented by one. Subtract one from the X register and store the new counter back in the X register. To update the X register, fill in the boxes below in the order in which you execute this instruction.

If this is the first time you have executed this instruction, look back at the value in the X register in instruction 4 and subtract one. Put the new value for X in the X register in box #1 below.

If this is your second time at this instruction, update the X register in box #2.

MEMORY

Address	Value	
$600	(LDX)	
$601	4	
$602	(LDA)	
$603	0	
$604	(CLC)	
$605	(ADC)	
$606	5	
$607	(DEX)	<—
$608	(BNE)	
$609		
$60A	(STA)	
$60B		
$60C		
$60D	(RTS)	
$60E		

#1. 6502
ACC. 0 5
X REG.

#3. 6502
ACC. 0 F
X REG.

#2. 6502
ACC. 0 A
X REG.

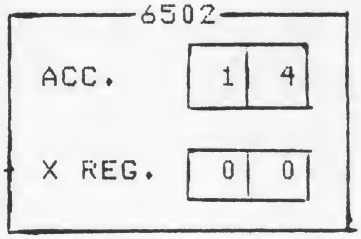
#4. 6502
ACC. 1 4
X REG.

6. BNE ADD: Is the number in the X register equal to zero? If not, branch back to instruction 4 and repeat instructions 4 and 5. If the counter in the X register is equal to zero, continue with instruction 7 below.

7. STA $060E: In order to save your answer, store the accumulator in memory location $60E.

MEMORY

Address	Value
$600	(LDX)
$601	4
$602	(LDA)
$603	0
$604	(CLC)
$605	(ADC)
$606	5
$607	(DEX)
$608	(BNE)
$609	
$60A	(STA) <——
$60B	
$60C	
$60D	(RTS)
$60E	<——



8. BRK: The last instruction in the program, BRK, instructs the CPU to discontinue execution of the program. In this case the program will be discontinued because we are done. The results of the series of additions are stored in memory.

If you experiment with typing this program into the assembler editor you can see the results of the program using the debugger. After you have assembled the program and you have the EDIT prompt on the screen, type BUG. From the debugger you can type DR and <RETURN> to display the contents of the registers. The accumulator should still hold the sum. The other option is to diplay the contents of memory location $60E which also holds the sum.

In order to understand slightly more complicated assembly language programs you must be familiar with two more registers in the 6502, the program counter and the stack pointer.

The Program Counter:

The program counter is a 16 bit (2 byte) register in the 6502. The program counter must be two bytes, because it holds a memory address and all addresses are two bytes. The program counter holds the address (the location in memory) of the next instruction to be executed in a program. As a program is running, the program counter is continually updated to the address of the next instruction the CPU will execute. The program counter keeps a watchful eye on your program! It tells the 6502 where to find the instructions to execute next.

The Stack Pointer:

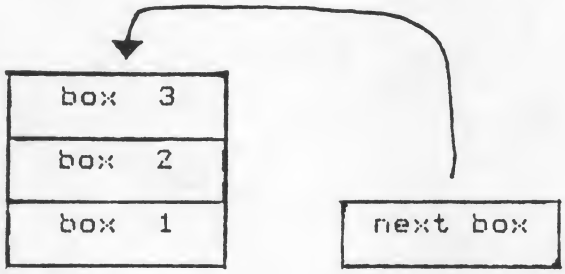
The stack pointer holds the address of the next available location in an area of memory called the "stack." The stack pointer is called a "pointer," because it holds an address and thus, is said to be pointing to a location in memory.

The stack is a set of 256 memory locations set aside for temporary data storage. The stack resides in memory locations $0100 - $01FF, which is also referred to as "page one" of memory. The high order byte (2 digits on the left) of the addresses on page one of memory are all $01, ($01<u>00</u>-$01<u>FF</u>). Since the high order byte of all the addresses on the stack is $01 only one byte is required for the stack pointer. Look back at Diagram 7 on page 41. Note that the stack pointer is shown as a one byte register. Also note the $01 infront of the register to indicate that the high order byte of any address held in the stack pointer will be $01.

```
      $01   00000000 = Stack Pointer
       \ /     \ /
 High Byte    Low Byte
is constant   A number between 0 and 255 which
              indicates the location on page
              one where the stack is located.
```

Data is stored on the stack in a very systematic way. A "last-in, first-out" (LIFO) filing system is used. The last byte of data stored on the stack is always the first byte you get off the stack.

One way to better understand the stack is to think of it as a tower of heavy boxes. As each new box is added to the tower, it is put on top of the stack of boxes.



To get to box #2 in the stack, first the top box and then box #3 must be taken down. Remember, these are heavy boxes, so you can lift only one at a time. Regardless of which box you want, boxes must be removed continually from the top of the pile until the desired box is reached. Thus, the last box to be put on the stack will always be on top and the first box to be taken off the stack will always come from the top of the stack of boxes.

Because of the "last-in, first-out" filing system of the stack, programmers should carefully plan the order in which they place data on the stack for later retrieval.

Now let's look at an example of the steps the computer takes to complete a program that includes using the stack. Turn to Machine Architecture Worksheet #8.

Machine Architecture Worksheet #8

This time you will execute a program which solves the equation 2*(3 * 8). Use a pencil so you can change the values in the registers and memory as you execute the program. The assembly language routine is listed below. Once again, you are not expected to completely understand the assembly language program. The instrucions will be explained in the Assembly Language Module. Our intent here is to familiarize you with the microprocessor, and how it executes assembly language programs.

```
       *= $0600       ;STORE PROGRAM STARTING AT $600 IN MEMORY
    SUM = $061C       ;LOCATION FOR SUM
  TOTAL= $061D        ;SAVE MEMORY FOR TOTAL
       CLC            ;CLEAR THE CARRY BIT
       LDY #2         ;LOAD Y REG. TO MULTIPLY BY 2
TWICE  LDX #3         ;LOAD X WITH 3 TO COUNT ADDITIONS OF 8
       LDA #0         ;LOAD ACC. WITH ZERO TO START
 ADD   ADC #8         ;ADD 8 TO ACCUMULATOR
       DEX            ;DECREMENT X REGISTER BY 1
       BNE ADD        ;IS X REG. = 0?   NO, ADD AGAIN
       PHA            ;PUT VALUE IN ACCUMULATOR ON STACK
       DEY            ;DECREMENT Y REGISTER BY 1
       BNE TWICE      ;IS Y REG. = 0? NO, MULTIPLY 3*8 AGAIN
       PLA            ;PUT LAST VALUE PUT ON STACK IN ACC
       STA SUM        ;STORE THE CONTENTS OF ACC IN MEMORY
       PLA            ;PUT FIRST NUMBER PUT ON STACK IN ACC
       ADC SUM        ;ADD SUM TO NUMBER IN ACC
       STA TOTAL      ;STORE TOTAL IN MEMORY
       BRK            ;DISCONTINUE PROGRAM EXECUTION
```

1. *= $600: This instruction indicates that the program will be loaded into memory starting at $600. The next two lines which contain the variables SUM and TOTAL followed by an equals sign are instructions which reserve memory locations for each of those variables.

2. CLC: Once again we will overlook the "CLear the Carry bit" command to the CPU.

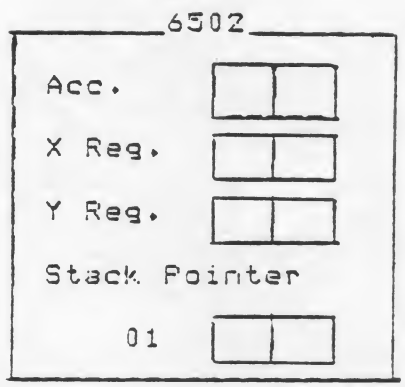
3. LDY #2: Load the Y register with the number 2, which is stored in memory following the LDY instruction. The Y register will serve as a counter for multiplying (3 * 8) by 2. Put a 2 in the Y register on the following page.

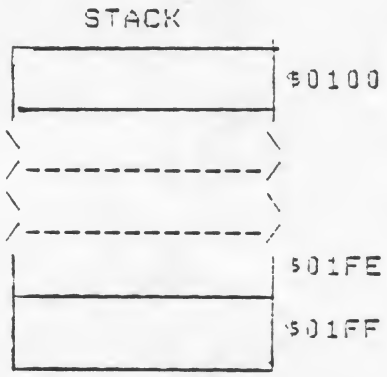
4. LDX #3: Now load the X register with a 3. We are multiplying by 3, by adding 8 three times. In this example both the X and the Y registers will be used as loop counters.

5. LDA #0: Load the accumulator with zero to start.

MEMORY

Address	Value
$600	(CLC)
$601	(LDY)
$602	2
$603	(LDX)
$604	3
$605	(LDA)
$606	0
$607	(ADC)
$608	8
$609	(DEX)
$60A	(BNE)
$60B	
$60C	(PHA)
$60D	(DEY)
$60E	(BNE)
$60F	
$610	(PLA)
$611	(STA)
$612	
$613	
$614	(PLA)
$615	(ADC)
$616	
$617	
$618	(STA)
$619	
$61A	
$61B	(BRK)
$61C	
$61D	





6. ADC #8: Now add 8 to the contents of the accumulator. Simply erase the number already in the accumulator, and replace it with the updated value. Remember to store the values in the registers and memory as hexadecimal numbers.

7. DEX: Decrement the X register by subtracting one from the contents of the X register and storing the new count back in the X register. The number in the X register indicates how many times 8 has been added to the value in the accumulator.

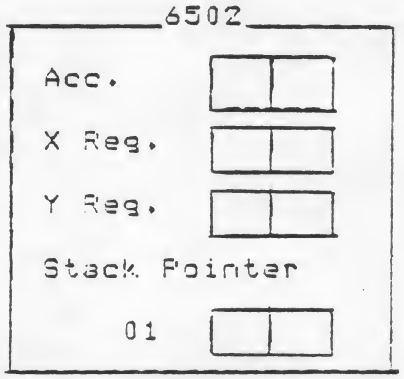
8. BNE ADD: Is the number in the X register zero? If not, branch to instruction 6 and complete instruction 6 and instruction 7 again. By redoing 6 and 7, you are adding on another 8 to the accumulator in order to compute the (3 * 8) part of the equation. When the X register is zero, you are ready to go on to instruction 9. Continue to execute the program, using the memory and CPU on the following page.

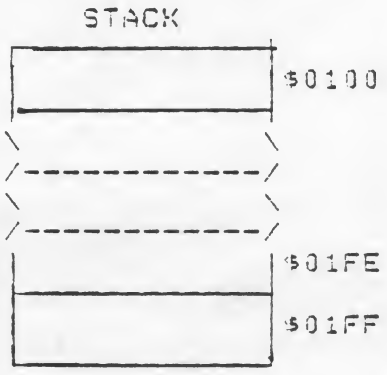
9. PHA: "PHA" stands for PusH the Accumulator onto the stack. This instruction tells the CPU to store a copy of the value in the accumulator on the stack. We need to save a copy of the accumulator on the stack in order to free the accumulator to add three eights a second time. The stack fills from the highest address on the stack down to the lowest, with one exception. The first value put on the stack is stored in memory location $0100. The second value put on the stack goes in $01FF. Each new value put on the stack is stored from the top down ($01FF down to $0101). Make a copy of the contents of the accumulator from the previous page in the accumulator below. Push the value in the accumulator onto the stack. Remember to use hexadecimal numbers.

The stack pointer holds the address of the next available location on the stack. When the stack is empty, the stack pointer is $00. The stack pointer must be updated as well. Put $FF (or $FE if this is the second time you have executed this instruction) in the stack pointer.

MEMORY

Address	Value
$600	(CLC)
$601	(LDY)
$602	2
$603	(LDX)
$604	3
$605	(LDA)
$606	0
$607	(ADC)
$608	8
$609	(DEX)
$60A	(BNE)
$60B	
$60C	(PHA)
$60D	(DEY)
$60E	(BNE)
$60F	
$610	(PLA)
$611	(STA)
$612	
$613	
$614	(PLA)
$615	(ADC)
$616	
$617	
$618	(STA)
$619	
$61A	
$61B	(BRK)
$61C	
$61D	





10. DEY: To decrement the Y register, subtract one from the contents of the register on page 51. The Y register holds the counter for the number of times (3 * 8) has been calculated. Record the contents of the Y register on page 52.

11. BNE TWICE: BNE stands for "branch not equal to zero." Is the number in the Y register equal to 0? If not, then branch back to instruction 4 and re-execute instructions 4 - 10. If the Y register is zero then continue with instruction 12.

12. PLA: "PLA" is the opposite of a PHA. PulL off the last value put on the stack and put it in the Accumulator. The PLA instruction erases the value from the stack and stores the value in the accumulator. Remember to update the stack pointer. This time add one to the stack pointer, so that it points to the next available location.

13. STA SUM: Store the contents of the accumulator in memory location $61C which has been reserved for the variable SUM. This will enable us to save the SUM of 8+8+8 for later use.

14. PLA: Now pull the first value you stored on the stack off and put it in the accumulator. Erase the value in the stack, record it in the accumulator, and update the stack pointer. Since there is nothing left on the stack, the stack pointer gets reset to $0100.

15. ADC SUM: Add the contents of the memory location $61C (SUM) to the contents of the accumulator. The two products of (3 * 8) are being added. Again the computer is completing a multiplication problem by adding. Update your accumulator with the result of the addition. Remember to use hexadecimal numbers.

16. STA TOTAL: Store the contents of the accumulator in memory location $61D, the memory location which has been reserved for the TOTAL. The answer to 2*(3 * 8) is now stored in memory and ready for any further use. Depending on what instructions followed this subroutine, the answer might be printed on the screen, or added to another number.

17. BRK: BRK instructs the computer is discontinue execution of the program. BRK instructions are commonly used to isolate a problem when debugging assembly language programs. In this case we used a BRK instruction to end the program.

You have just completed most of the steps the processor would go through to execute this assembly language program. Did that seem like a lot of work for solving 2*(3 * 8)? Amazingly enough the 6502 could execute the same program in a split second!

Follow the next six instructions to observe the computer execute the program you just completed by hand. You will need the Assembler Editor cartridge and the Advanced Topics Diskette to do this. Put the Assembler cartridge in the slot on the left where your BASIC cartridge ordinarily goes, and boot your diskette.

1. You should have the EDIT prompt in the upper left hand corner of your screen. Load the EQUATION file on your Advanced Topics Diskette.

Type: Enter D:EQUATION and press <RETURN>

2. Type LIST and press <RETURN>. You should see the program you just executed by hand listed on the sceen.

3. Your program needs to be assembled to machine code by the assembler and stored in memory.

Type: ASM and press <RETURN>

4. In order to look at the contents of specific memory locations and the registers, you need to get into the debugger.

Type: BUG and press <RETURN>

5. The debugger also enables us to "step" through the program and observe the computer executing one instruction at a time. The first instruction of the program is at $600.

Type: S600 and press <RETURN>

The "S" stands for step. At the bottom of the screen you should see the machine code contained in memory location $600, the corresponding assembly language instruction, and the contents of the internal registers as shown below.

```
600       18       CLC
     A=00  X=00  Y=00  P=30  S=00
```

The 600 is the hexadecimal address of the memory location. The 18 is the machine code for the assembly language instruction CLC. The next line lists the contents of the internal registers. The A, X, and Y are self-explanatory. The P stands for the Processor Status register, which we will cover in the next section, and the S represents the stack pointer.

6. Now Type: S and press <RETURN>

The LDY #2 instruction was just executed and the registers were updated. Step through the program by typing "S" and <RETURN> after each instruction has been executed. Compare your total with the number in the accumulator when you reach the BRK instruction. The answer or TOTAL was stored in memory location $61D. To see what is stored in $61D,

Type: D61D and press <RETURN>

The first "D" stands for display, followed by the memory location you wish to see. Is the computer's TOTAL the same as yours?

7. To see how fast the computer executes the EQUATION program,

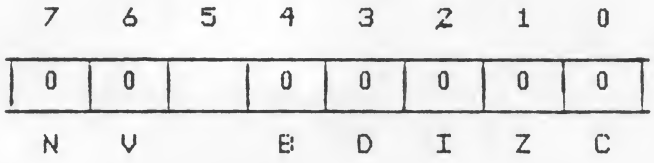
Type: G600 and press <RETURN>

The "G" stands for "GO" or execute the program which is stored in memory starting at $600. The BRK instruction at the end of the EQUATION program terminates the program and returns you to the debugger.

Processor Status Register:

The status register is last register which we will use commonly in assembly language programming. The status register is also a one byte register. However, instead of the byte holding a number such as an address, each of the eight bits of the byte means something different. For example, one bit indicates if there is a negative number in one of the internal registers. Another bit indicates if there is a zero in one of the registers. The processor status register information is based on the results of the 6502's most recent computation. Diagram 8 shows the significance of each bit. Don't worry if you don't fully understand what the status bits are at this point.

Diagram 8



N = Negative Result. Indicates whether the result of an arithmetic operation was a negative number.

V = Overflow. Indicates whether the result of a mathematical calculation was larger than 255, the maximum number which can be stored in one byte.

An unused bit.

B = Break Command. Indicates whether there has been a break in the 6502's processing.

D = Decimal Mode. Controls whether the math operations will be computed in binary or decimal mode.

I = Interrupt Disable. Controls the interruptions to the 6502's processing.

Z = Zero Flag. Indicates whether the result of the most recent calculation was a zero.

C = Carry Flag. If the answer to an addition problem is greater than 255, which is the largest quantity an 8 bit byte can hold, the carry bit is set.

Each of the eight bits is comparable to an on/off switch. If the bit is a one, it is said to be "set" or on. A zero indicates that the condition does not exist (the switch is off) and the bit is "clear." The bits of the status register are referred to as "flags."

Suppose you just calculated 5-7. The result is negative, and consequently the sign flag (bit 7) of the status register will be set to one. Other flags will also be set by this computation. They will be discussed later.

Status Register

7	6	5	4	3	2	1	0
1	0	0	0	0	0	0	0
N	V		B	D	I	Z	C

↑

Suppose the most recent calculation was 7-7. As a result, the sign flag would be clear, but the zero flag (bit 1) would be set to 1.

Status Register

7	6	5	4	3	2	1	0
0	0	0	0	0	0	1	0
N	V		B	D	I	Z	C

↑

Turn to Machine Architecture Worksheet #9, to have a look at the contents of some of the registers and how they are displayed.

Machine Architecture Worksheet #9

You will need an Assembler Editor cartridge and your Advanced Topics Diskette to complete this worksheet.

1. Boot up the system. The EDIT prompt should be in the upper left hand corner of the screen.

Type: ENTER #D:EQUATION and press <RETURN>

2. The EDIT prompt is still in the upper left hand corner.

Type: ASM and press <RETURN>

You will see the assembly language version of the program going by on the screen as it is being converted to machine language.

3. Now Type BUG and press <RETURN>. This puts you in the debugger, where you can look at what is stored in the registers. You should see the DEBUG prompt on the screen.

4. To run the EQUATION program,

Type: G600 and press <RETURN>

This stands for GO $600, which runs the assembly routine from its starting address at $600. The program stops because of the BRK instruction at the end of the program and the contents of the registers are displayed. Since you ran the program from the debugger, you are returned to the debugger.

5. Record the values of the different registers below.

Accumulator	X Reg.	Y Reg.	Processor Status	Stack Pointer
A =	X =	Y =	P =	S=

Note that the values are listed in hexadecimal.

6. Convert the value in the Processor Status Register to an eight bit binary number.

P = $_____ = _____ in base 2.

7. According to the binary byte you got, which of the status register flags are clear and which are set?

N	V		B	D	I	Z	C

	Set	Clear	(Check One)
N = Negative flag			
V = Overflow flag			
B = Break command			
D = Decimal mode			
I = Interrupt disable			
C = Carry flag			

The unused flag is set whenever a program is run. The break flag is set due to the break instruction at the end of the program.

Summary

The 6502 microprocessor contains six registers:

Accumulator: Used for math operations and data transfer.

X Register: Used for data transfer and as a counter to a loop.

Y Register: Used for data transfer and as a counter to a loop.

Program Counter: Holds the address of the next instruction to be executed.

Stack Pointer: Holds the address of the next available location on the stack.

Processor Status Register: Has seven flags reflecting the results of the most recently executed instruction.

Executing a program involves a repeated transfer of program instructions and data back and forth between memory and the 6502 microprocessor. The processor fetches each instruction from memory one at a time. It executes the instruction and then fetches the next instruction to be executed. The CPU uses its registers to hold the data which is manipulated.

To learn more about machine architecture and assembly language programming, you might want to read The ATARI Assembler by Don and Kurt Inman which is available in the camp library. Plan to proceed with the Assembly Language Module to learn more about the assembly language instruction set and how to program in assembly language.

Challenges

1. Write and hand-process an assembly language program to count to 100 by 10.

2. Write and execute a program that solves the equation (5 * 8) + 3. (HINT: Use the EQUATION program as a model.)

Additional Chips

In addition to the 6502 microprocessor, the ATARI has the Antic, GTIA, and Pokey chips, which enhance the graphics, and sound of the computer. Each chip is explained briefly below. These are specialized chips which make the Atari different from other microcomputers on the market.

Antic:

The Antic chip is a microprocessor devoted entirely to handling television display. The Antic chip is programmable, just as the 6502 is. The programs written for the Antic chip are called display lists. To find out more about the Antic chip and display lists, see the Display List Module.

GTIA:

The GTIA chip, a fairly recent addition to the Atari computer, replaced the old CTIA chip. The GTIA chip increases the range of colors available to the programmer and offers three additional graphics modes (9,10,11). Antic controls most of the GTIA's operations.

POKEY:

POKEY performs a number of functions involving input and output. It handles the transfer of information between memory and the CPU along the Data Bus, as well as sound, reading the keyboard, and random number generation.

Table 9.6—INTERNAL CHARACTER SET

Column 1				Column 2				Column 3				Column 4			
#	CHR	#	CHR	#	CHR	#	CHR	#	CHR	#	CHR	#	CHR	#	CHR
0	Space	16	0	32	@	48	P	64		80		96		112	p
1	!	17	1	33	A	49	Q	65		81		97	a	113	q
2	"	18	2	34	B	50	R	66		82		98	b	114	r
3	#	19	3	35	C	51	S	67		83		99	c	115	s
4	$	20	4	36	D	52	T	68		84		100	d	116	t
5	%	21	5	37	E	53	U	69		85		101	e	117	u
6	&	22	6	38	F	54	V	70		86		102	f	118	v
7	'	23	7	39	G	55	W	71		87		103	g	119	w
8	(	24	8	40	H	56	X	72		88		104	h	120	x
9	)	25	9	41	I	57	Y	73		89		105	i	121	y
10	*	26	:	42	J	58	Z	74		90		106	j	122	z
11	+	27	;	43	K	59	[	75		91 ①		107	k	123	
12	,	28	<	44	L	60	\	76		92		108	l	124	|
13	—	29	=	45	M	61	]	77		93		109	m	125 ①	
14	▬	30	>	46	N	62	^	78		94		110	n	126 ①	
15	/	31	?	47	O	63	—	79		95		111	o	127 ①	

1 In mode 0 these characters must be preceded with an escape, CHR$(27), to be printed

Hexadecimal to Decimal Conversion

To convert a hexadecimal number using the chart below, use the digits on the vertical border of the chart to represent the high order nybble of your hexadecimal byte. The digits on the horizontal border of the chart represent the low order nybble of the hexadecimal byte. So if you want to convert $10 to a decimal number, first look for 1 on the vertical number line, and then look for 0 on the horizontal numbers. Follow the two digits towards the center of the matrix and you find that $10=16.

Hex and Decimal Conversion

LSD →	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	
0	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	0
1	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1
2	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	2
3	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	3
4	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	4
5	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	5
6	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	6
7	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	7
8	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	8
9	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	9
A	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	A
B	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	B
C	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	C
D	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	D
E	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	E
F	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	F
	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	

```
                10 ;PRINT A MESSAGE TO THE SCREEN BY
                20 ;PLACING THE INTERNAL CHARACTER
                30 ;SET VALUE DIRECTLY IN SCREEN
                40 ;MEMORY     FILE: TEXT
                50 ;*****************************
                60 ;
0000            0100          *=   $0600
0600 A905       0110          LDA  #$5        ;MESSAGE LENGTH
0602 85CD       0120          STA  $CD
                0130 ;
                0140 ;$CD IS A FREE BYTE ON THE ZERO PAGE.
                0150 ;THE MESSAGE LENGTH IS BEING STORED THERE
                0160 ;
0604 A000       0170          LDY  #00        ;COUNTS EACH LETTER AS OUTPUT
0606 B91106.    0180 LETTER   LDA  $611,Y     ;GET THE NEXT LETTER
0609 9158       0190          STA  ($58),Y    ;PUT LETTER ON NEXT SCREEN LOCATION
060B C8         0200          INY             ;INCREMENT LETTER COUNTER
060C C4CD       0210          CPY  $CD         ;THE END OF THE MESSAGE?
060E D0F6       0220          BNE  LETTER      ;NO, GET ANOTHER LETTER
0610 60         0230          RTS
0611 28         0240          .BYTE 40,37,44,44,47
0612 25
0613 2C
0614 2C
0615 2F
```

```
100 REM *  A PROGRAM TO FILL THE SCREEN WITH ONE INPUT CHARACTER
110 REM *
120 REM ************************************************************
130 REM *
140 DIM A$(1):REM DIMENSION INPUT STRING
150 PRINT "PRESS ANY KEY";
160 INPUT A$:REM LETTER TO FILL SCREEN
170 FOR I=1 TO 874
180 PRINT A$;:REM OUTPUT CHARACTER
190 NEXT I
200 GOTO 150
```

```
10 REM *                  FILLSCREEN
20 REM *
30 REM *  A PROGRAM WHICH FILLS THE SCREEN WITH ONE LETTER
40 REM *  ACCORDING TO THE MOST RECENT KEYPRESS.  AN ASSEMBLY
50 REM *  LANGUAGE ROUTINE IS POKED INTO MEMORY STARTING AT
60 REM *  1536 ($600) USING THE DECIMAL VALUES FOR THE MACHINE
70 REM *  CODE LISTED IN DATA LINES 220-250.  THE PURPOSE
80 REM *  OF THIS PROGRAM IS TO DEMONSTRATE THE SPEED OF AN
90 REM *  ASSEMBLY LANGUAGE ROUTINE.
95 REM ************************************************
100 REM *
110 REM *  LINES 140-180 READ THE ASSEMBLY ROUTINE
120 REM *  DATA AND POKE IT INTO MEMORY
130 REM *
140 PROGRAMLEN=74:REM ASSEMBLY ROUTINE IS 75 BYTES LONG (0-74)
150 FOR CODE=0 TO PROGRAMLEN
160 READ INSTRUCTION
170 POKE 1536+CODE,INSTRUCTION
180 NEXT CODE
190 REM *
200 REM *  ASSEMBLY ROUTINE DATA
210 REM *
220 DATA 104,104,104,141,77,6,201,0,240,23,201,32,48,4,201,95,48,9,24,105
230 DATA 64,141,77,6,76,33,6,56,233,32,141,77,6,165,88,133,203,165,89,133
240 DATA 204,169,3,141,76,6,169,152,141,75,6,173,77,6,160,0,145,203,230
250 DATA 203,208,2,230,204,206,75,6,208,243,206,76,6,16,238,96
260 PRINT "PRESS ANY KEY";
270 OPEN #2,4,0,"K:"
280 GET #2,CHARACTER
290 REM *  CALL EXECUTES THE ASSEMBLY ROUTINE IN MEMORY
300 CALL=USR(1536,CHARACTER)
310 GOTO 280
```

```
                0100 ;  FILLS THE GRAPHICS 0 SCREEN
                0110 ;  WITH A CHARACTER PASSED FROM
                0120 ;  A BASIC PROGRAM.
                0130 ;  FILE : FILL
                0140 ;**********************************
                0150 ;
0000            0160        *=   $CB
00CB            0170 SCREEN =    *
00CB            0180        *=   $0600
0600 A941       0190        LDA  #65        ;GET CHARACTER VALUE,A
0602 8D4C06     0200        STA  CHR        ;SAVE CHARACTER HERE
                0210 ;
                0220 ;CONVERT THE ATASCII VALUE TO THE INTERNAL CHARACTER SET VALUE
                0230 ;
                0240 ;
0605 C900       0250        CMP  #0         ;SPACE
0607 F017       0260        BEQ  BEGIN      ;DISPLAY CHARACTER
0609 C920       0270        CMP  #32        ;IS ATASCII 32 OR LESS?
060B 3004       0280        BMI  ADD        ;YES, ADD 32 FOR INTERNAL CHARACTER SET
060D C95F       0290        CMP  #95        ;IS ATASCII 95 OR LESS?
060F 3009       0300        BMI  SUB        ;THEN SUBTRACT 32 FOR INTERNAL CHAR VALUE
0611 18         0310 ADD    CLC             ;CLEAR THE CARRY
0612 6940       0320        ADC  #64        ;ADD 64
0614 8D4C06     0330        STA  CHR        ;STORE INTERNAL CHARACTER VALUE IN CHAR
0617 4C2006     0340        JMP  BEGIN      ;DISPLAY
061A 38         0350 SUB    SEC
061B E920       0360        SBC  #32        ;SUBTRACT 32, ATASCII TO INTERNAL CHARS
061D 8D4C06     0370        STA  CHR
                0380 ;
                0390 ; SET UP SCREEN RAM AND OUTPUT COUNTERS
                0400 ;
0620 A558       0410 BEGIN  LDA  $58        ;START ADDRESS SCREEN RAM
0622 85CB       0420        STA  SCREEN     ;FREE LOCATION ON ZERO PAGE
0624 A559       0430        LDA  $59        ;HIGH BYTE SCREEN RAM
0626 85CC       0440        STA  SCREEN+1   ;FREE LOCATION ON ZERO PAGE
0628 A903       0450        LDA  #03        ;HIGH COUNT VALUE
062A 8D4B06     0460        STA  CNT2
062D A998       0470        LDA  #152       ;LOW COUNT VALUE
062F 8D4A06     0480        STA  COUNT
                0490 ;
                0500 ; LOOP TO FILL THE SCREEN
                0510 ;
0632 AD4C06     0520        LDA  CHR
0635 A000       0530        LDY  #00         ;INDEX
0637 91CB       0540 FILL   STA  (SCREEN),Y ;DISPLAY
0639 E6CB       0550        INC  SCREEN     ;INCREMENT ADDRESS LOW BYTE
063B D002       0560        BNE  SKIP1      ;IF NOT 0,BRANCH TO SKIP1
063D E6CC       0570        INC  SCREEN+1   ;ADD TO HIGH BYTE
063F CE4A06     0580 SKIP1  DEC  COUNT      ;COUNT BYTES DONE
0642 D0F3       0590        BNE  FILL       ;IF NOT ZERO, FILL
0644 CE4B06     0600        DEC  CNT2       ;16 BIT ARITH
```

```
0647 10EE   0610         BPL  FILL        ;UNTIL DONE
0649 60     0620         RTS              ;DONE - RETURN TO BASIC
            0630 ;
            0640 ; DATA STORAGE AREA
            0650 ;
064A        0660 COUNT   *=   *+1         ;HIGH COUNT VALUE
064B        0670 CNT2    *=   *+1         ;
064C        0680 CHR     *=   *+1         ;CHARACTER VALUE
```